Play, Dreams and Imitation in *Robota*

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Abstract

What if we were to have a robot we could play with? What if we could through play and daily interactions, as we do with our children, be a model for it and teach it (what?) to be human-like? There is an important market for "intelligent" toys and there is still room for innovation. I advocate the use of natural human-like interaction, such as imitation, speech and gestures, for developing likable, pet-like toys. As an example, I present two prototypes of doll-shaped robots, the Robota dolls, which can engage in complex interaction with humans, involving speech, vision and movement imitation.

Introduction

The title of this paper is a wink to the Swiss psychologist, Jean Piaget. In his book "*Play, Dreams and Imitation in Childhood*", Piaget stressed the importance of play behavior and in particular of imitative games as a key developmental stage in children. Imitation is a powerful means of teaching as well as of learning. One can learn from good and bad examples. By observing someone else's behavior, one can learn new skills or learn to avoid doing similar mistakes. It is a learning mechanism more efficient and less costly than trial and error.

Roboticists would benefit from the possibility of implementing a control mechanism allowing the robot to learn new skills (which would otherwise require complex programming) by the sole ability of observing another agent's performance. Imitation can be the direct means of learning the skill, as in the case of learning new motor skills (see, for instance, (Dautenhahn 1995), (Demiris & Hayes 1996), (Gaussier *et al.* 1998), (Cooke *et al.* 1997), (Kuniyoshi & Inoue 1994), (Schaal 1999)). It can also be an indirect means of teaching. For instance, the robot's ability to imitate the teacher can be used to lead the robot to make specific perceptual experiences upon which the robot grounds its understanding of a proto-language (Billard 1999b; Billard & Hayes 1999; 1998).

Entertainment robotics aims to create playful autonomous creatures. For psychologists (starting with Piaget), children's games are as much an educational tool as an entertainment device. An interesting toy is often a toy which offers a challenge, where, by playing with the toy, one discovers many means of using it. This can be true of the simplest toy, such as a wooden stick (which can be used as a litt, a drill, a bridge or a limb as part of a stick figure). A boring toy is a toy whose use is limited and immediately understood. Thus, an interesting robotic toy should show several means of interaction with the child. These should include responding to touch and handling, gestures, vocal expression and, if possible, speech.

Imitation is an interesting game, as it offers a wide variety of interaction. One can imitate gestures, postures, facial expressions, behaviors, where each of the above relates to a different social context. My earlier mentioning of Piaget's work meant to recall that imitation is also an important means of teaching and as such might offer important possibilities for toys.

What if we were to have a robot we could play with? What if we could through play and daily interactions, as we do with our children, be a model for it and teach it (what?) to be human-like?

Making one's toy more personal is the wish of most children. Tools of artificial intelligence which provide adaptive and learning abilities or allow to simulate development are very suitable for this purpose. Proof is the large success encountered by the video game *Creatures*, the Japanese electronic devices *Tamagochi* and toy robots, such as the LEGO *Mindstorms*, the *Furbys* and the Sony pet robot.

There is an important market for "intelligent" toys and there is still room for innovation. I advocate the use of natural human-like interaction, such as imitation, speech and gestures, for developing likable, pet-like toys. As an example, I present two prototypes of doll-shaped robots, the Robota dolls, which can engage in complex interaction with humans, involving speech, vision and motor imitation.

I wish to mention that the first Robota was designed for academic research purpose, namely to investigate the use of connectionist controllers for experiment on robot learning by imitation. Experiments were carried out in which the robot could be taught a proto-language to describe its interaction with the teacher, such as that of motion and of perception of touch on different parts of its body. The robot has the ability to imitate the arm and head movements of the human. By so doing, it can be taught sentences to describe its actions. Further, it can learn combinations of movements, simple dance patterns. This work has been reported elsewhere (Billard 1999b; 1999a). In this paper, I present recent hardware and software developments, namely the development of the second prototype of Robota, which makes the robot a possible toy. Figure 1 shows a picture of the two robots, the first prototype on the left and the second on the right.

Figure 1: The two Robota dolls. The first prototype is on the left and the second prototype on the right.

The rest of this paper is organized as follows. The first section describes the two robots' mechanics and controller. The second part briefly summarize experiments I carried out with them. I conclude the paper with a brief outlook of what I wish the future of the Robota dolls to be. In the remainder of the paper, I will use the term Robota for describing both the first and second prototypes I developed. I coined the term to describe the concept of an interactive learning doll robot, independently of a particular mechanical implementation of it.

The doll robots

Robota I

The first prototype of Robota is made out of LEGO parts for the body and of plastic components of a commercial doll for the arms and the head (see figure 2). Inserted in the body are three LEGO motors to drive the arms and the head. The robot is provided with five touch sensors (electrical switches), placed under the feet, inside the hands and the mouth, a tilt sensor which measures the vertical inclination of the body (it distinguishes between horizontal and vertical positions) and

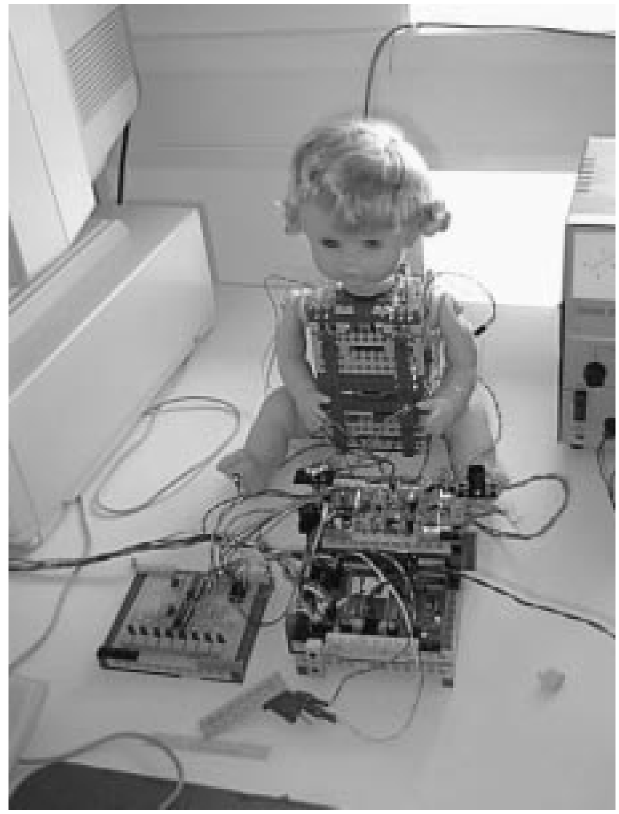

Figure 2: The first prototype of Robota is made out of LEGO parts for the body and of plastic components of a commercial doll for the arms and the head.

four infra-red (IR) detectors. Each infra-red detector consists of an emitter and a receptor. Two of the IR receptors are placed on the robot's chest and measure the signals of the corresponding IR emitters which the demonstrator holds, one in each hand. The imitative behavior of the doll is enabled through the infra-red set-up. The signal of each sensor is used to control each of the robot arms. That is, when the demonstrator moves his/her left arm in front of the robot, the right detector on the robot is activated, which triggers the robot's right arm waving movements, i.e. lifting the arm up and then down with a fixed time interval between the two movements. The two other IR emitters are placed on the robot's ears, while the two corresponding IR receptors are mounted onto a pair of glasses which the demonstrator wears. Phototaxis performed on the two IR signals is used to direct the robot's head. That is, when the demonstrator looks, e.g. to the left, the left detector on the glasses receives full activation while the right one receives none, which triggers the robot's head movement to the left, i.e. the robot turns the head to the left (and vice-versa for the right). After a fixed time delay (about half a second), the robot moves the head back to facing the demonstrator. As a result, the robot appears to mirror the demonstrator's arm and head movements.

The robot is provided with a simple communication system, which consists of a keyboard and a loudspeaker (which is a commercial pocket recorder with 20 seconds recording time). The pocket recorder is used by the demonstrator to record sounds, spoken words or sentences (a sound slot lasts for 2 seconds), which correspond to the conceptual meaning the demonstrator attaches to each key of the keyboard. The demonstrator communicates with the robot by pressing the keys on the keyboard, each key representing a different word; the robot answers the demonstrator by reading back the sound slots of the corresponding words of the keyboard.

The robot controller is made of a micro-controller with 512k byte EPROM space and 128k byte Static RAM. The CPU (central Processing Unit) is a Phillips 93C100 series 68000 compatible running at 30 MHz. All electrical circuits is external to the robot. Sensors and motors are connected via external wires.

Robota II

The second prototype, Robota II, has the same abilities for imitation and communication as that of the first prototype, but each module is much more sophisticated. Here is a list of the enhancements brought to the second prototype.

- In addition to moving the arms and the head, the second Robota can walk forwards and backwards by making small saccadic stepping.
- The body of the robot is that of a commercial doll. The mechanics for driving the motors is entirely contained in the body.
- The microcontroller and electronic interfaces are onboard of the robot, attached as a backpack (see figure 4).
- The robot has a rechargeable battery of 30 minutes duration, which is contained in the backpack. The robot can also be powered externally through a power supply. It requires about 2 to 4A at 6V.
- It has a electronic magnet inside the right hand which allows it to hold a baby bottle. Aside the magnet is a switch which allows the robot to detect when an object is inserted in its hand.
- It has numerous sensors (switches on the hands, head, mouth, leg, inclination sensor, IR-proximity sensors, pyroelectric sensor for detecting human movements).
- Similarly to the first prototype, the second robot can be connected to external devices: a pair of glasses and a pair of hand sensors for the imitation set-up (see figure 3) and a keyboard. The keyboard contains a set of eight keys, a microphone, a 6-positions joystick and a chip (PIC), preprogrammed to play one note of the musical scale for each of the eight keys. That is, the 8-keys of the keyboard is an electronic xylophone. The robot has also a microphone inside the

Figure 3: **Top:** The teacher guides the robot's motions using a pair of glasses holding a pair of IR emitter. The glasses radiation which can be picked up by the robot's "earrings" IR receptors. **Middle** The robot is provided with switch sensors on the hands, feet and mouth, which allows it to detect touch on these parts of its body. **Bottom:** The second Robota can connect through a serial link to a PC. This allows one to interact with the robot through speech and vision.

body which allows it to repeat the sounds. The joystick can be used to direct the robot's arm and head movements (lifting up and down the arm and shaking the head on the sides). This provides an additional mean, on top of the infra-red mirroring set-up, to direct the robot's arm and head movements.

- The robot can connect through a serial link to a PC. I developed a program which allows one to interact with the robot through speech and vision. The program uses a commercial speech processing (for French and English) for translating speech into strings of words (written language). Sensor and actuator states are passed as variables through the serial link. The program implements the DRAMA learning algorithm (see below). It is used to let the robot learn a language from listening to the user and associating the speech strings to its perception of the world, see the next Section.

  The PC is connected to a QuickCam CCD camera. A recognition system for motion (visual flow), intensity fluctuation and skin color detection is used to let the robot moves or produces sound or speech when it detects some environmental variation. The program can also start-up music (MP3 files or CDs). This is used to provide the robot with play behavior. The robot spontaneously puts on a music and starts dancing (i.e. moving backwards-forwards and making head and arm movements), making a different dance for each music.

  The DRAMA learning algorithm runs also on the robot and allows the robot to learn melodies (as played by the user on the keyboard) and to learn dance patterns for each melody (by associating sequences of movements with sequences of notes).

  The code for the PC is written in C and C++ and runs both under linux and windows 95/98. It was tested on a HP4100 laptop, Pentium II, 266MHz, 96M and was shown to run on real time.

The robots' controller

In the two prototypes, the robot behavior and learning is controlled by the DRAMA architecture (Billard & Hayes 1999). DRAMA stands for Dynamical Recurrent Associative Memory Architecture. It is a connectionist model which allows learning of spatio-temporal correlations and of time series. It is based on Hebbian rules and is computationally cheap, thus allowing learning to be carried out on-line and on-board of the robot (Billard & Hayes 1998; 1997). A complete description of the model can be found in (Billard & Hayes 1999), we here briefly summarize its main properties.

The robot controller is composed of two parts: a set of *event recognition* modules for detecting variations in the robot's sensor-actuator state and a *learning module*, the DRAMA architecture, which associates sequentially the changes across all the sensor-actuator modalities of the robot. At each processing cycle, the sensor-actuator state vector is measured. When a variation (i.e. more than one bit change) in one sensor or actuator input has been measured, the new information is forwarded to the associative architecture (DRAMA) to be correlated with all simultaneous and previously recorded events in other sensor-actuator systems.

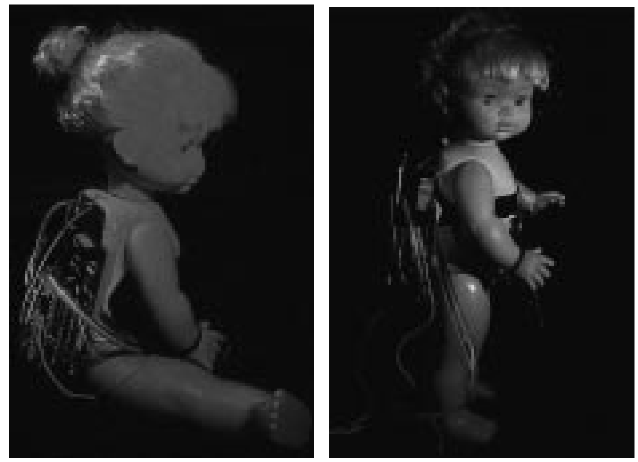

Figure 4: The second prototype of Robota is a standalone robot. It can be connected to a PC for speech and vision-based interaction. The reproduction of the photos are a courtesy of Eurelios.

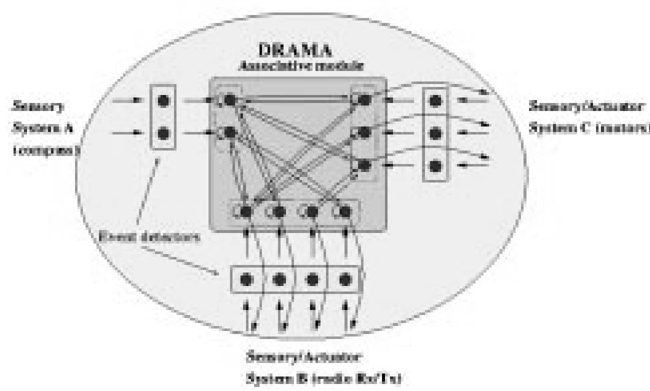

Figure 5: Schema of the connectionist architecture DRAMA which controls the imitative and learning skills of the robot.

DRAMA is a fully connected recurrent neural network, without hidden units. The self-connections on the units provide a short term memory of the units' activation. Consequently, sensor and actuator information (i.e. their corresponding network units' activation) is memorized for a fixed duration; the memory duration is determined by the decay rate of unit activation along the self-connection on the unit, see equation 1. This allows association to be made between time delayed presentations of two inputs, hence learning of time series. In the experiments, the robot learns sequences of actions (dance patterns), i.e. consecutive activation of different actuator states. It also learns words to label its perceptions, i.e. it associates labels (radio signal or combination of typed keys on a keyboard) with other consecutive, simultaneous or precedent perceptions. Finally, it learns to combine sequentially the labels to form proto-sentences and to associate these combinations with a meaning in terms of other perceptual inputs. Figure 5 shows a schematic representation of the controller with three sensor systems as inputs.

Long term memory of consecutive activation of two units in DRAMA consists of updating the parameters of the connection linking these two units following pseudo-Hebbian rules (see equations 3 and 4). Similarly to time-delay neural networks, each connection in the DRAMA network has two associated parameters: a time parameter (τ) and a confidence factor (w). Time parameters and confidence factors are positive numbers; they record respectively the time delay between two units' activations and the number of their co-activations.

Unit activation function

$$y_i(t) = F(x_i(t) + \tau_{ii} \cdot y_i(t-1) + \sum_{j \neq i} G(\tau_{ji}, w_{ji}, y_j(t-1))) \quad (1)$$

F is the identity function for input values less than 1 and saturates to 1 for input values greater than 1 ($F(x) = x$ if $x \leq 1$ and $F(x) = 1$ otherwise) and G is the retrieving function whose equation is given in 2. w_{ji} is the weight of the connection leading from unit j to unit i.

$$G(\tau_{ji}, w_{ji}, y_j(t-1)) = A(\tau_{ji}) \cdot B(w_{ji}) \quad (2)$$

$$A(\tau_{ji}) = 1 - \Theta(|y_j(t-1) - \tau_{ji}|, \epsilon(\tau_{ij}))$$

$$B(w_{ji}) = \theta(w_{ji}, \delta(w_{ij})\frac{\max_{y_j>0}(w_{ji})}{T})$$

$\Theta(x, H)$ is a threshold function that outputs 1 when $x >= H$ and 0 otherwise. ϵ is an error margin on the time parameter. It is equal to $0.1 \cdot \tau_{ij}$ in the simulations, allowing a 10% imprecision in the record of the time delay of units coactivation. The term $\delta(w_{ij})$ is a threshold on the weight. It is $\frac{\max_{y_j>0}(w_{ji})}{\theta(w_{ij})}$. $\theta(w_{ij}) = 2$ in the experiments of Section 2. $\max_{y_j>0}(w_{ji})$ is the maximal value of confidence factor of all the connections between activated units j and unit i, which satisfy the temporal condition encoded in $A(\tau_{ji})$.

Training rules

$$w_{ji}(t) = w_{ji}(t-1) + a \quad (3)$$

$$\tau_{ji}(t) = \frac{\tau_{ji}(t-1) \cdot \frac{w_{ji}}{a} + \frac{y_j(t)}{y_i(t)}}{\frac{w_{ji}}{a} + 1} \quad (4)$$

The DRAMA network has general capacities for learning of spatio-temporal regularities and time series. A formal analysis of these properties can be found in (Billard & Hayes 1999). The network can learn series of the type 1) ABA, cyclic sequence; 2) $ABCDE$ and $HJCKAE$, crossing sequences on state C and A; 3) $ABCDEFCDG$, sequence with a loop on states CD and divergence on state D. These properties are very relevant to learning of a language, which is made of multiple combinations of the same primary items (words) and where sentences are often recursive combinations of the same instances. For instance, $ABCDEFCDG$ could represent the sentence 'I think that you should recognize that you are wrong' and ABA could represent '(To be) (or not) (to be)'. $ABCDE$ and $HJCKE$ could be "My parents work at home", "I will work from home".

Built-in behaviors can easily be defined by presetting particular sensor-actuator connections. For instance, the Robot's ability to mirror the hand and head movements results from presetting particular connections between light sensors (sensitive to visual and infra-red light) and the robot's motors. Recall of the DRAMA units' outputs (following equation 1) is used to direct the robot's movements (retrieval of the predefined sensor-motor connectivity). Results of the learning can then be immediately exploited. For instance, recall of learning of motor sequences (dance movements) and of sequences of speech strings in Robota, results in the robot's immediate repetition of the sequence when prompted to do so, i.e. when the robot is presented with the associated stimulus (the music for the dance and the sensor perception for speech).

Experiments

As mentioned in the Introduction, the learning abilities of the robot were demonstrated earlier on in experiments in which the robot was taught "dance patterns" (different sequences of arm and head movements) as demonstrated by a human teacher. Further, it was taught a proto-language to describe its interactions with the demonstrator. It learned words for describing its different body parts (head, foot, mouth, arm) and learned to compose these words to produce proto-sentences (e.g. I move left arm, you touch mouth, etc.). A description of these experiments can be found in (Billard 1999a; Billard, Dautenhahn, & Hayes. 1998). I wish to focus here on the potential of the robot as a toy.

Tests with children

The robot doll was tested with nine children of five years old (six boys and three girls). The game consisted in having the children teach the robot different words to describe meaningful arm movements (by using the robot's imitation abilities) and touch perception (by pressing the switches on the robot's body). The words were: 'food', 'rocking', 'hello' (right arm up), 'Yeah' (two arms up), 'No' (side movements of the head), 'hand', 'left foot', 'right foot'. The robot was provided with a behavior which led it to cry out as long as it was not fed or rocked. As soon as the children had taught the words food and rocking, then the robot would speak up the word when hungry, therefore solving the ambiguity of the crying message.

The children took a real pleasure in the fact that the doll was responding to their touching her. Little behaviors such as small random movements of the head and arms had been implemented as a reaction to the child touching the switches on the doll's hands, feet and mouth. The robot would then appear to sometimes wave the head from left to right when the child

Figure 6: Kyo Takiguchi 'feeding' Robota

tried to feed it, as if it did not want to be fed. The children liked also the fact of being able to command the robot's arms and head movements, although they took less pleasure in this than in touching the robot. One reason is probably that they do not control well enough their own movements yet and thus had problems to direct correctly the robot's movements. For the robot to respond correctly to head and arms' movements, you had to make very precise movements (lift the arms straight and in a narrow region around the middle of the robot's body, and small slow sideways movements of the head). The children had problems achieving such precision. It was not clear whether all children had really understood the learning process behind the robot's speaking, that is the relationship between their touching the robot, pressing the keys, and the robot's consequent speaking, especially as some children would press the wrong key, which would result in the robot speaking a different word than the expected one. These observations suggest that the game reached the limits of competence of so young children, as it required from them to concentrate for a long period of time on a repetitive task. However, we should mention that most of the children were keen on continuing playing with the doll after they had been told that the game was finished (each game lasted for about 20 minutes; this limit was chosen in order not to exceed the concentration capacity of young children). None of the children had had time to teach the entire vocabulary during the game, nor to understand fully all the different capabilities of the robot (especially to understand all the correlations between their acting on the robot and the robot's movements and speaking). The complexity of the robot seemed to intrigue them rather than to intimidate them.

An Educational Tool

As part of the project Aurora[1] (Dautenhahn 1999), the robot was presented at a school for autistic children. Seven children of age 8 to 11 were allowed to play with the robot in turn. The level of cognitive and motor competence of the children varied enormously, as some children were capable of fluent speech and other not, as is the case for autistic children. However, all children showed interest in the game, taking pleasure in directing the robot (through the mirror mechanism) and getting the robot to speak. A main limitation of autistic children is their deficiencies in engaging in social interaction and in particular to engage in eye contact. An important part of the teachers' efforts is devoted to attract the child's attention and to get the child to interact with others. They often use toys, generally simple but very colorful and noisy toys, as an interface to engage in two persons + toy interaction. In this context, the attention which Robota received from the children led the teachers to think that it could potentially make an interesting teaching tool. As the level of complexity of the game with Robota can be varied (e.g. using only the imitation game versus using the learning abilities of the robot), the robot could be used to test the child's motor and linguistic competences (an important means of evaluating the deepness of autism).

The future of Robota

After their presentation at the European Conference on Artificial Life (ECAL'99) last September, the Robota dolls have received some media coverage. This led me to receive genuine correspondence from children and adults who expressed their interest in a more clever version of an old toy, as is a doll.

Moreover, the success encountered during the tests with children suggests that indeed the robot might make an interesting toy, used for pure entertainment as well as a teaching device.

The Robota doll employs several means of interaction. It can react to touch and handling (inclination), to human presence (pyroelectric sensor and camera), to simple joystick commands, to music (CDs and xylophone-keyboard) and to speech. It allows for different levels of interaction from simple motor command, imitation to learning of motor skills and speech.

The second prototype is a standalone autonomous robot (all the electronic is contained in the body). When connected to a PC, it can increase its simple abilities to handling speech and vision. The interactive PC program runs on a standard set-up. It seems that several elements are in place to make the Robota's commercialization plausible. It remains to find a possible sponsor!

[1] The project Aurora is directed by Dr. Kerstin Dautenhahn at the University of Reading. It is funded by the British governmental agency for science and aims at developing mobile robotic platforms for teaching autistic children.

Acknowledgments

I built the first prototype of Robota in my spare time aside doing a PhD thesis at the University of Edinburgh. The mechanical components were put together collaboratively with my ingenious boy-friend, Auke Jan Ijspeert. The electronics was developed at the department of Artificial Intelligence at the University of Edinburgh. The second Robota doll was built at the Laboratory of MicroInformatics at the Swiss Institute of Technology in Lausanne (EPFL), thanks to the generosity of Professor Jean-Daniel Nicoud, who also developed the electronic interface which drive the motors and sensors. The main electronic board, Kameleon, is a commercial product developed by K-Team SA. I am responsible for the design of both robots and for the development of their control systems.

I am very grateful to Alexander Colquhun, David Wise at the University of Edinburgh and Olivier Carmona, Yuri Lopez de Meneses and Rene Beuchat at the LAMI for their very precious help in the long and foreboding process of debugging the electronic system for each robot.

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